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July 26, 2011

VIA ELECTRONIC MAIL

Nigel B. Cooney, Esq. (nigel.cooney@usdoj.gov)
Sumona N. Majumdar, Esq. (sumona.majumdar@usdoj.gov)
U.S. Department of Justice
Environment & Natural Resources Division
Ben Franklin Station
P.O. Box 7611
Washington, DC 20044-7611

Re: Tradition Investments, LLC - § 308 CWA Request Work Plan

Dear Mr. Cooney and Ms. Majumdar:

Pursuant to our discussions, enclosed for USEPA's review and approval is our final § 308 CWA Request Work Plan for the Tradition South Dairy site in Jo Daviess County, Illinois. Attached is both a clean, final Work Plan as well as a redlined copy showing the changes from the draft submitted in June, 2011 which was the subject of our discussions.

This final Work Plan addresses all of the issues enumerated in your July 14, 2011 correspondence. Please note that slug testing of the shallow boreholes is not proposed. The purpose of the shallow, overburden wells is to (i) provide water table elevations relative to the bedrock water levels measured at the paired bedrock borrowings; and, (ii) provide real time data during packer testing of the bedrock borings to evaluate potential responses at the overburdened aquifer. The converse, however, is not true. Slug testing overburden water table wells will only provide response data for the region immediately surrounding the well screen and will not provide any definitive information regarding hydraulic relationship between the overburden with the underlying bedrock. As such, no shallow overburden well slug tests are proposed in the Work Plan.

Note that the proposed schedule has been updated to reflect opportunities for USEPA review and consultation of results as the project proceeds; however, these timelines are necessarily restricted given the need to avoid remobilization and to otherwise keep the work on schedule as reflected in the Work Plan schedule.

MICHAEL BEST
& FRIEDRICH LLP

We look forward to USEPA's prompt approval within a week of receipt so that the field work can commence.

Very truly yours,

MICHAEL BEST & FRIEDRICH LLP

David A. Crass

Enclosures

cc via email: Donald Q. Manning, Esq. (dqm@mjwpc.com)

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§ 308 CWA REQUEST WORK PLAN

TRADITION SOUTH DAIRY

JO DAVIESS COUNTY, ILLINOIS

July 26, 2011

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NEWFIELDS

NewFields
2110 Luann Lane, Suite 101
Madison, Wisconsin 53714

§ 308 CWA Request Work Plan
Tradition South Dairy
Jo Daviess County, Illinois

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§ 308 CWA Request Work Plan
Tradition South Dairy
Jo Daviess County, Illinois

1.0 Introduction

This work plan has been prepared in response to the U.S. Environmental Protection Agency's ("USEPA") July 2010 Information Request issued pursuant to § 308 of the Clean Water Act (Docket No. V-W-10-308-33) ("the 308 Requests"). This work plan describes the methodology to be used to conduct the studies called for by the 308 Requests, following discussions with USEPA. The area of concern includes the footprints of three proposed clay-lined manure storage basins at the Tradition South Dairy facility in Jo Daviess County, Illinois, and immediately adjacent land. The basins include two east-west trending 1200' × 400' in-ground structures (north and south), and one north-south trending 150' × 900' in-ground structure (west). At the present time, only the north and west basins have been excavated; the recompacted clay liners have not yet been constructed. Construction is scheduled to begin in 2011.

2.0 Project Background

The Tradition South facility is located in eastern Jo Daviess County, Section 6, Township 28 N, Range 5 East, south of Warren and west of Nora, Illinois. Jo Daviess County is part of the Driftless Area, a geologic feature occupying much of northwest Illinois, eastern Iowa, southeastern Minnesota and southwestern Wisconsin. The origin of the Driftless Area name is based on its geologic history of the area that shows little evidence of erosion caused by continental glaciation. Karst features have been mapped in Jo Daviess County by the Illinois State Geological Survey. The nearest mapped karst features (e.g. sinkholes) are approximately 11 miles to the southwest and covers less than 1/3 of a square mile.

The site was investigated in accordance with the requirements of the Illinois Livestock Management Act to evaluate subsurface conditions including soil type, bedrock and water table proximity in preparation for basin construction. Borings were advanced and the bedrock cored prior to excavation. During construction of the north and west basins, additional test pits and soil probes were advanced for further definition of the bedrock surface. A plan view of the final basins design including existing and proposed topography, and locations of soil borings, test pits and probes is shown on Figure 1.

USEPA first issued an information request concerning the Tradition South Dairy in April 2009 pursuant to Section 308 of the Clean Water Act (CWA). Subsequent responses from the dairy were followed by supplemental requests from the Agency through July 2010. The July 2010 Agency request sought performance of various studies to confirm the presence or absence of "karst" features at the subsurface areas beneath the Dairy's "holding ponds." The request specified that this information would be obtained through a field program consisting of various studies including the performance of:

- A geophysical investigation to evaluate subsurface anomalies within the area of the basin indicating potential karst features in the underlying bedrock;
- A natural voids study of the Tradition South area to inspect possible sinkholes and other collapse features;

- A stream study in the area of Tradition South to evaluate potential losing streams, and select proposed sampling stations for both background and tracer dye exposure points;
- A man made voids study intended to allow for introduction of tracer dye (if no natural voids or other collapse features are determined in the basin study area), and
- A tracer test study to confirm the presence or absence of karst features that may adversely affect the proposed basins operation.

Subsequent discussions concerning the scope and approach to these requested studies among Tradition and USEPA representatives were conducted during the fall 2010 and winter 2011 and included the exchange of conceptual investigation plans, Agency comments and responses. An on-site meeting at the Tradition facility was held on April 18, 2011. As a result of these discussions, the scope and focus of the July 2010 request has been refined and the project approach has been confirmed. This detailed work plan has been developed in accordance with these latest discussions and is submitted for USEPA review and approval.

3.0 Technical Approach

Subsurface information developed as part of the basins' design defined that the ground surface in the area is underlain by silty clay loess (classified CL/CH by the Unified Soils Classification System), which in turn is underlain by Ordovician Galena dolomite. At a few borings, the loess was underlain by silty clay residuum (CH) likely formed from alteration of younger Maquoketa Shale that overlies the Galena north of the Tradition South property. However, shale was not identified in any site borings. The nearest occurrence of the shale, a known aquitard, was documented in borings advanced approximately one mile to the north. Based on private well logs in the area, the Galena underlies the overburden from 50 to 200 feet thick. The local private well logs also show the Galena dolomite is underlain by up to 150 feet of limestone-dolomite of the Platteville Formation. These carbonate bedrock units comprise the water supply aquifer for the surrounding region. These data also indicate no aquitard is likely present causing confined or perched aquifer conditions within the area of the manure basins.

The depth to bedrock within the basins' footprints varies from five feet (measured from finished clay at the top of liner grade) at the northwest corner of the north basin, to approximately 12 feet (measured from existing ground surface) near the southern perimeter of the south basin. The slope of the bedrock surface toward the southeast approximates the ground surface slope. No monitoring wells were required as part of the subsurface investigation at the Tradition South site. However, static water levels measured in site borings confirmed the water table is present within the overburden clays. As a result, an underdrain pipe system was designed and partially installed (for the north and west basins) to prevent groundwater encroachment into the excavations and to ultimately protect the constructed liner from hydrostatic uplift (see Figure 1).

These data inform the approach Tradition South proposes for this work plan. An initial geophysical investigation using electrical methods will be conducted at each of the three basins. This effort will evaluate variations in electrical conductivity or resistivity that may be associated with changes in, among other things, saturated porosity, fracture density, clay content/in-filling, voids, pore fluid conductivity, and non-in situ fill. Results from this initial geophysical investigation are intended to provide data to detect or delineate potential locations for potential dye introduction through boreholes drilled into the dolomite.[1]

As indicated on the enclosed schedule, the results of the geophysics investigation will be evaluated immediately following completion. Suspect anomalies within the basins' footprint, if any, will be evaluated and representative dye introduction points selected for intrusive drilling. The number and location of proposed drill sites will be determined by the geophysics results in consultation with USEPA. An all-terrain vehicle (ATV) drilling rig will then be mobilized to the site to advance borings into the bedrock at the selected candidate drill points.[2] This drilling program is intended to complete the man made voids study.

Bedrock boreholes drilled at selected locations will be evaluated for suitability for dye introduction through packer tests. This will consist of isolating the bedrock mass from the overburden and determining the rate at which water can be added to the bedrock and analyzing its response to changes in water pressure. Minimum criteria for suitability of a dye introduction point are: A rate of water addition of the equivalent of one-quart per minute at one atmosphere of pressure for the duration of the test and an appropriate response to changes in pressure (see Royle attached, cases 3, 4, and 9 pp.15-18 for examples of appropriate response).

Following completion of all field studies, a final report summarizing the investigation findings and conclusions will be prepared.

4.0 Scope of Work

The following narrative includes the detailed scope of work for the tasks outlined above. It describes the methods and rationale to complete the investigation requirements. These requirements include the geophysical investigation, a background stream study, man made voids study (drilling and aquifer packer tests) and subsequent tracer tests.[3]

4.1 Geophysical Investigation

Two electrical methods will be used to complete the geophysical program. These include a capacitance coupled resistivity (CCR) dipole-dipole survey and an electromagnetic (EM) survey. The CCR method can map detectable variations in electrically resistive rock and soils (e.g., limestone, sand, and gravel). CCR pseudosections can be modeled to yield geologic cross-

[1] During the April 18, 2011 on-site meeting, both the north and west basins were partially inundated. In preparation for this study, Tradition began actively removing this water, and will maintain drained conditions until the geophysics and subsequent potential dye introduction program is complete.
[2] An ATV drill will be required to traverse the 3:1 side slopes at the north and west basins.
[3] Based on the information presented at the onsite meeting, no natural voids have been found in the area of the basin footprints that may be considered for dye injection. This is because the site has been severely altered during historical farming as well as during recent excavation and construction activities. Accordingly, no natural voids study will be performed.

sections. The cross-sections can provide detail that often assists with locating a void, soil filled void, or fracture/joint system. The EM method will generate similar data as the CCR method, but is less sensitive and has a shallower depth of penetration. Because of the current configuration of the existing and planned basins, both will be applied at the Tradition South site.

The CCR method will be performed along east-west transects spaced 20 feet apart at the proposed south basin, and along one linear north-south transect congruent with the long axis of the west basin. Data will be collected at stations spaced an average of 10 feet apart along each transect. While transect lines will be placed along the proposed basin's north wall, the geometry of the CCR method will only permit data acquisition within approximately 150 feet of the basin footprint measured from the base of the slope. However, the geometry of the proposed survey at the unexcavated south basin, along with the single transect within the west basin, should provide sufficient data detail. This geometry should allow for data from approximately 40-foot depths, below the identified bedrock surface. The data collected at the west basin and along two additional transect lines will yield CCR pseudosections. The locations of the two other transect lines will be determined in the field.

Because of the steep excavation walls, the EM method will be performed at the north basin over accessible areas. An EM31 instrument, approximately 12 feet in length will provide an average depth of penetration of approximately 18 feet. Although shallower than the depths provided by the CCR array, the thin overburden beneath the excavation floor (five to six feet) will provide a depth into the bedrock only slightly less than that from the CCR survey.

During the April 18, 2011 on-site meeting, the limitations caused by the steep excavation walls as well as the potential for the investigation to identify anomalies beyond the influence of the basins were identified and discussed. Accordingly, the proposed layout for both the CCR and EM arrays are shown on Figure 2.

4.2 Background Stream Study

The two unnamed streams that originate on or cross the Tradition South property will be examined for springs. The examination will be limited to a visual search and measurements of pH, temperature, and specific conductivity. The search will be conducted downstream to where the streams cross Route 78.

A comprehensive sampling network will be established prior to performing the man made voids study (see Section 4.3). This network will include any springs identified and large enough to be potentially recharged from the site. These springs will be selected from interviews with neighboring property owners, tenants, and other knowledgeable people, such as members of the local historical society. The sampling network will consist of at least two activated carbon samplers placed at stream road crossings and at any springs large enough to likely receive waters from the site (by placing two samplers at each location, duplicates will be collected for quality control purposes; additionally, the second sampler insures a backup if a sampler is damaged, lost, or stolen). Any springs not directly sampled will be indirectly sampled at downstream sampling stations. The actual stream station plan will be determined after the interviews and inspection are performed. However, based on published information as well as a current understanding of the area, a network of four control and 23 dye sampling points are shown on Figure 3.

Control point stations will also be established at streams near the site. These stations will be sampled to detect possible extraneous fluorescent compounds. These background and control data will provide limits on ambient conditions that could interfere with the interpretation of tracer results.

The coordinates for all selected stream sample stations will be determined in the field with a hand held GPS device. These data will be downloaded to Tradition's Access database established using US, Illinois, State Plane NAD83, Illinois West, U.S. feet coordinate system. This database interfaces with a GIS platform (ArcGIS 9.3.1) that will allow determination of the distance from each station to the basins. Following establishment of the network, these data will be exported to a table that will include the station coordinates, distance to the basins, observed approximate discharge (for identified springs) and other pertinent observations made during the field inspection. The table will then be submitted to USEPA for comment.[4]

Two background sampling events will be performed. The first round of water and carbon samples will be analyzed prior to selecting the dye type and quantity, and the subsequent background sampling event will be analyzed concurrent with dye introduction. All background samples will be analyzed and used to interpret the dye tracing data.[5]

4.3 Man Made Voids Study/ Drilling and Packer Testing

The data developed during the geophysical survey will be evaluated and in consultation with the geophysicist, proposed drill locations will be selected. These selected drill sites and the rationale for each will be submitted to USEPA for review and discussion in a conference call to be convened within one week of submittal. Although the actual number and position of the drill sites will be determined, for planning purposes a minimum of six sites within the geophysical

[4] All springs that discharge from bedrock within the comprehensive surface sampling network shown on Figure 3 of the work plan will be identified. If a bedrock spring is considered not relevant to the investigation, the justification for that opinion will be described to USEPA. With the Agency's concurrence, the subject spring will be eliminated from the sampling network. As shown on the project schedule, the first of two background sampling events will be performed upon establishment of the sampling station network. If the Agency believes that any spring identified as not relevant should be reconsidered for sampling, USEPA is requested to contact the Tradition field staff before completion of the initial sampling event.

[5] It can take one to two weeks for the laboratory turnaround from the date of field collection. As shown on the attached schedule, the second background sampling event will be collected beginning one week following completion of the first event. Carbon samplers will be placed immediately following collection of the first background sample. This will allow the second sample to be collected before the introduction of dye. Accordingly, fresh samplers will be re-established immediately prior to dye introduction to ensure that any fluorescence can be properly attributed to the post-dye introduction time period. Although the final round of background samplers will not be analyzed prior to dye introduction, this procedure follows the proper field methodology.

study area will be selected. A conceptual layout of six drill sites within the basin area is shown on Figure 4.

Two borings will be advanced at each drill location. One will be drilled to the top of bedrock using 6¼-inch inner diameter (ID) hollow stem augers (HSAs). At auger refusal a temporary PVC two-inch diameter well screen and riser will be installed. This well will be constructed as a water table well with the appropriate screen length (up to 15' as necessary) intersecting the water table. A pressure transducer will be placed in the temporary well to monitor water levels.

The second boring will be drilled adjacent to the first also using 6¼-inch ID HSAs. At auger refusal a temporary four-inch ID steel casing will be advanced within the HSAs using air rotary methods. This casing will be seated within the bedrock a short distance (several inches to one-foot), and then sealed with bentonite along the outside of the casing as the augers are retracted. Following auger removal a 3½-inch outer diameter (OD) core barrel will be advanced through the steel casing into the bedrock using air rotary supply methods. The core barrel will be advanced in five- or ten-foot runs. Each run will be properly logged by a qualified geologist and catalogued for type, rock characteristics, fracture occurrence and frequency, rock quality designation and percent recovery. Each bedrock boring will be cored to a target depth sufficient to evaluate karst conditions in the vicinity of the basins. This depth will be determined by the geophysics and drilling conditions encountered, but a nominal elevation of 935' msl is assumed (The 935' elevation is the minimum previously investigated at the site; this depth compares to 971' top of bedrock elevation at the northwest corner of the north pond, to 956' top of bedrock elevation south of the south pond at the head of the tile-fed drainage ditch). When coring is complete the packer will be placed at a depth below the temporary casing based on the results of the coring lithology.

After the packer is inflated, a pressure transducer will be placed above the packer. Two types of tests will be conducted through the packers. The first will be a traditional packer test with three increasing steps followed by two decreasing pressure steps. Each step will have its pressure and cumulative water flow recorded at one minute intervals. When three consecutive, equal (steady state) measurements are recorded during each pressure application), the test will progress to the next step. If the appropriate response is observed during the pressure measurements such as discussed in Section 5.0 in the attached (Royle), then a second packer test will be performed as described below.

Water will then be added to and pressure maintained in the boring through the packer for a minimum of three hours or until 500 gallons of water has been introduced into the bedrock to determine whether or not the boring meets the criteria for dye introduction.[6]

No packer test will be performed with applied pressures exceeding the calculated total lithostatic pressure to prevent hydrofracturing of the bedrock. The pressure transducer at the subject

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[6] Tradition recommends that there should be no more than a 24-hour delay between packer testing and dye introduction. If no borehole meets the minimum criteria, the attached schedule shows a contingency of one additional week to allow USEPA review of the packer test data prior to borehole abandonment.

borehole and the pressure transducer at the adjacent temporary well in the overburden will be monitored during the test for increases in pressure that will indicate short circuiting of flow around the packer. If short circuiting is measured, the packer will be lowered and the test repeated until the baseline pressure above the packer or the adjacent overburden well is not increased.

During the drilling program daily water levels will be collected at each temporary well/ bedrock borehole pair following removal of the packer equipment. These data will confirm the extent of the water table aquifer in the basin study area and if any perched or confined aquifer conditions are present. At the conclusion of the final packer test, the horizontal coordinates (in accordance with the Illinois State Plane coordinate system) and top of casing elevations at the bedrock borings and temporary wells will be surveyed. Following completion of the dye introduction program, the temporary wells and bedrock borings will be properly abandoned.[7]

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4.4 Tracer Test

Prior to establishing the sampling network, pH, temperature, and specific conductivity will be measured at nearby springs (as practical) and at field tile discharge points as references. These data will be recorded in a field log book. These parameters will also be measured and recorded at the background sampling stations. These parameters will be measured at any springs included in the sampling network along with their estimated discharge. Discharge will be estimated by estimating average velocity, overall channel width, and average depth. All sampling locations will be photographed and recorded with a GPS device.

Primary reliance will be placed on activated carbon samplers because they sample continuously and accumulate dye. These samplers essentially lower the practical detection limit for any given dye. Grab samples of water at stream stations will also be collected at each location whenever a sampler is placed or replaced. These grab samples will only be analyzed if there is no carbon sampler, if there is dye in the associated charcoal sampler, or at the discretion of the field geologist. Grab samples can act as confirmation samples and will be the only samples in the chain of custody at all times. However, it is common for water samples to be nondetect for dye, when the carbon sampler yields a detection as it has accumulated dye since placement.

A sampling network will be established for the detection of dye. While it is likely that flow will remain within the topographic basin, the sampling network will be sufficiently comprehensive to detect dye in the event of interbasin transfer in any direction.

The network shown on Figure 3 is preliminary. Some upstream reaches may be dry and may be impractical. The stations shown at Spring Creek, several miles to the east, are only included

[7] Abandonment procedures will be performed in accordance with Illinois Administrative Code Title 77, Chapter I, Subchapter r, Part 920, Section 920.120. In accordance with these regulations, a neat cement slurry mixture (5 gallons of water per 94 lb bag of cement that can include up to five percent bentonite) will be delivered via tremie pipe and the boring filled to the ground surface. For the overburden monitoring wells, the well casings will be properly removed and the borings abandoned using the same method as that for the bedrock borings.

because of the name. If the presumptive springs that are the cause of the name of this creek are small, these sampling stations will likely be eliminated.

Two rounds of background sampling lasting approximately one week each will be collected prior to borehole dye introduction. At least one round of background samples including both carbon and water samples will be analyzed prior to dye introduction. Because the area is rural, significant interference from background fluorescence is not anticipated.

Dye type and quantity will be based on the results of the first round of water and carbon background analysis as well as the longest distance to a sampling station. However, it is anticipated that the dye selected will be either fluorescein, eosine, or rhodamine WT. Sufficient dye will be used to achieve a detection that is at least 10 times background (if any) at the most distant sampling station. The dye will be introduced prior to demobilizing the packer testing equipment if any of the borings exceed the threshold criteria for dye injection upon analysis of the packer test results (Section 4.3). If one boring transmits significantly more water than the others, that boring will be selected for dye introduction. If there are multiple borings that meet or exceed the minimum criteria and have similar ability to transmit water into the bedrock, each will be used as a dye introduction point. The same dye will be introduced at each dye introduction point if multiple dye introduction points are used. The dye will be flushed with a minimum of 2,500 gallons of potable water. The flushing water will move the dye out of the boring and into conduits with natural flow thus expediting the trace.

Sampling will be on a schedule of decreasing frequency. The purpose of the schedule is to provide reasonable time of travel data. An initial sample will be collected one day after dye introduction, followed by a second sample two days after dye introduction, a third sample four days after dye introduction, a sample seven days after dye introduction, and then weekly samples for six weeks. Beginning at seven weeks after dye introduction, samples will be collected approximately every other week until termination. Termination of sampling will be determined by the longest straight line distance to a sampling station divided by 50 feet per day.[8]

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Sample collection will be documented in a field log book along with digital photographs. The date, time, and sampling station name and number will be recorded on the outside of the sample containers. The water sample will be collected in a disposable vial and the activated carbon placed in a Whirl-Pak® bag. Samples will then be chilled immediately to approximately 4° C until analysis. The collection data will be recorded on a data collection sheet provided by the laboratory (see Figure 5). Samples will be shipped overnight (chilled with blue ice in a cooler) to a laboratory for fluorescence analysis using a scanning spectrofluorophotometer. A laboratory that specializes in fluorescence analysis for dye tracing such as Ewers Water Consultants, Inc. will be used.

Detections must meet the laboratory's criteria for dye and must be at least 10 times any background fluorescence for that dye. Background fluorescence sampling will be performed at

[8] The minimum velocity at which Tradition's tracer subcontractor (Philip Moss) successfully performed a test in karst geology.

all locations during the background period and at control points after dye introduction.

Laboratory detection and reporting limits are typically less than 0.1 ppb for all of the dyes being considered.

If dye is credibly detected at a sampling point, a thorough search of that stream reach will be bracketed by a detection-non detection pair of samples for the spring or springs that discharged the dye. If a complete dye trace is successful, it is likely that the dye will discharge for more than a few days. A visual search will be performed of the discharge area and include measurements for pH, temperature, and specific conductivity. If necessary, a field fluorometer will be used to locate the relevant spring or springs (although field fluorometers can produce false positives, a detection will have been made by a laboratory using a scanning spectrofluorophotometer). If there is a positive detection in water, a field fluorometer will be used to detect fluorescence in water consistent with the dye from the downstream detection point to its upstream point of discharge. If there is no detection in the associated water sample, but only in the activated carbon sample, then no attempt will be made with a field fluorometer; reliance will be placed on visual observations and measurements of pH, temperature, and specific conductivity. If necessary, seepage runs will be conducted as well. Seepage runs are a series of stream flow measurements typically made with Pygmy current meters or similar devices at measured cross sections. A series of carefully measured stream discharges over a stream reach can identify gains or losses that are in excess of the method measurement error.

4.5 Report Preparation

The results of the above field studies will be compiled in a report presenting the findings and conclusions of the investigations. The report will be submitted to USEPA no later than 45 days of completion of the field studies.

5.0 Project Schedule

The geophysical investigation is anticipated to require one week for field data collection, followed by five days of data interpretation. Within this time frame, the stream sampling network will be established and the two background sample events performed. Candidate borehole locations will be selected following receipt of the geophysical results, and then submitted to the Agency for review and consideration as provided herein. Within one week of submittal, the Agency and Tradition South will confirm the final site locations. The drilling equipment will then be mobilized as soon as the schedule permits (assumed to be within one week of finalizing locations). The drilling program and packer test program is anticipated to require 10 to 14 days. If tracer test monitoring is performed, it is anticipated to require a maximum of 17 weeks from dye introduction.

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The proposed project schedule in the form of a Gantt chart is attached on the following page. This chart assumes the field program will begin within two weeks of work plan approval. It includes the various task durations linked as appropriate in accordance with the task descriptions previously described. It also shows separate timelines for completion of field activities along with the subsequent report with and without tracer tests.

§ 308 CWA REQUEST WORK PLAN

TRADITION SOUTH DAIRY

JO DAVIESS COUNTY, ILLINOIS

July 26, 2011

NEWFIELDS

NewFields
2110 Luann Lane, Suite 101
Madison, Wisconsin 53714

§ 308 CWA Request Work Plan
Tradition South Dairy
Jo Daviess County, Illinois

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Subsequent discussions concerning the scope and approach to these requested studies among Tradition and USEPA representatives were conducted during the fall 2010 and winter 2011 and included the exchange of conceptual investigation plans, Agency comments and responses. An on-site meeting at the Tradition facility was held on April 18, 2011. As a result of these discussions, the scope and focus of the July 2010 request has been refined and the project approach has been confirmed. This detailed work plan has been developed in accordance with these latest discussions and is submitted for USEPA review and approval.

3.0 Technical Approach

Subsurface information developed as part of the basins' design defined that the ground surface in the area is underlain by silty clay loess (classified CL/CH by the Unified Soils Classification System), which in turn is underlain by Ordovician Galena dolomite. At a few borings, the loess was underlain by silty clay residuum (CH) likely formed from alteration of younger Maquoketa Shale that overlies the Galena north of the Tradition South property. However, shale was not identified in any site borings. The nearest occurrence of the shale, a known aquitard, was documented in borings advanced approximately one mile to the north. Based on private well logs in the area, the Galena underlies the overburden from 50 to 200 feet thick. The local private well logs also show the Galena dolomite is underlain by up to 150 feet of limestone-dolomite of the Platteville Formation. These carbonate bedrock units comprise the water supply aquifer for the surrounding region. These data also indicate no aquitard is likely present causing confined or perched aquifer conditions within the area of the manure basins.

The depth to bedrock within the basins' footprints varies from five feet (measured from finished clay at the top of liner grade) at the northwest corner of the north basin, to approximately 12 feet (measured from existing ground surface) near the southern perimeter of the south basin. The slope of the bedrock surface toward the southeast approximates the ground surface slope. No monitoring wells were required as part of the subsurface investigation at the Tradition South site. However, static water levels measured in site borings confirmed the water table is present within the overburden clays. As a result, an underdrain pipe system was designed and partially installed (for the north and west basins) to prevent groundwater encroachment into the excavations and to ultimately protect the constructed liner from hydrostatic uplift (see Figure 1).

These data inform the approach Tradition South proposes for this work plan. An initial geophysical investigation using electrical methods will be conducted at each of the three basins. This effort will evaluate variations in electrical conductivity or resistivity that may be associated with changes in, among other things, saturated porosity, fracture density, clay content/in-filling, voids, pore fluid conductivity, and non-in situ fill. Results from this initial geophysical investigation are intended to provide data to detect or delineate potential locations for potential dye introduction through boreholes drilled into the dolomite.[1]

As indicated on the enclosed schedule, the results of the geophysics investigation will be evaluated immediately following completion. Suspect anomalies within the basins' footprint, if any, will be evaluated and representative dye introduction points selected for intrusive drilling. The number and location of proposed drill sites will be determined by the geophysics results in consultation with USEPA. An all-terrain vehicle (ATV) drilling rig will then be mobilized to the site to advance borings into the bedrock at the selected candidate drill points.[2] This drilling program is intended to complete the man made voids study.

Bedrock boreholes drilled at selected locations will be evaluated for suitability for dye introduction through packer tests. This will consist of isolating the bedrock mass from the overburden and determining the rate at which water can be added to the bedrock and analyzing its response to changes in water pressure. Minimum criteria for suitability of a dye introduction point are: A rate of water addition of the equivalent of one-quart per minute at one atmosphere of pressure for the duration of the test and an appropriate response to changes in pressure (see Royle attached, cases 3, 4, and 9 pp.15-18 for examples of appropriate response).

Following completion of all field studies, a final report summarizing the investigation findings and conclusions will be prepared.

4.0 Scope of Work

The following narrative includes the detailed scope of work for the tasks outlined above. It describes the methods and rationale to complete the investigation requirements. These requirements include the geophysical investigation, a background stream study, man made voids study (drilling and aquifer packer tests) and subsequent tracer tests.[3]

4.1 Geophysical Investigation

Two electrical methods will be used to complete the geophysical program. These include a capacitance coupled resistivity (CCR) dipole-dipole survey and an electromagnetic (EM) survey. The CCR method can map detectable variations in electrically resistive rock and soils (e.g., limestone, sand, and gravel). CCR pseudosections can be modeled to yield geologic cross-

[1] During the April 18, 2011 on-site meeting, both the north and west basins were partially inundated. In preparation for this study, Tradition began actively removing this water, and will maintain drained conditions until the geophysics and subsequent potential dye introduction program is complete.
[2] An ATV drill will be required to traverse the 3:1 side slopes at the north and west basins.
[3] Based on the information presented at the onsite meeting, no natural voids have been found in the area of the basin footprints that may be considered for dye injection. This is because the site has been severely altered during historical farming as well as during recent excavation and construction activities. Accordingly, no natural voids study will be performed.

sections. The cross-sections can provide detail that often assists with locating a void, soil filled void, or fracture/joint system. The EM method will generate similar data as the CCR method, but is less sensitive and has a shallower depth of penetration. Because of the current configuration of the existing and planned basins, both will be applied at the Tradition South site.

The CCR method will be performed along east-west transects spaced 20 feet apart at the proposed south basin, and along one linear north-south transect congruent with the long axis of the west basin. Data will be collected at stations spaced an average of 10 feet apart along each transect. While transect lines will be placed along the proposed basin's north wall, the geometry of the CCR method will only permit data acquisition within approximately 150 feet of the basin footprint measured from the base of the slope. However, the geometry of the proposed survey at the unexcavated south basin, along with the single transect within the west basin, should provide sufficient data detail. This geometry should allow for data from approximately 40-foot depths, below the identified bedrock surface. The data collected at the west basin and along two additional transect lines will yield CCR pseudosections. The locations of the two other transect lines will be determined in the field.

Because of the steep excavation walls, the EM method will be performed at the north basin over accessible areas. An EM31 instrument, approximately 12 feet in length will provide an average depth of penetration of approximately 18 feet. Although shallower than the depths provided by the CCR array, the thin overburden beneath the excavation floor (five to six feet) will provide a depth into the bedrock only slightly less than that from the CCR survey.

During the April 18, 2011 on-site meeting, the limitations caused by the steep excavation walls as well as the potential for the investigation to identify anomalies beyond the influence of the basins were identified and discussed. Accordingly, the proposed layout for both the CCR and EM arrays are shown on Figure 2.

4.2 Background Stream Study

The two unnamed streams that originate on or cross the Tradition South property will be examined for springs. The examination will be limited to a visual search and measurements of pH, temperature, and specific conductivity. The search will be conducted downstream to where the streams cross Route 78.

A comprehensive sampling network will be established prior to performing the man made voids study (see Section 4.3). This network will include any springs identified and large enough to be potentially recharged from the site. These springs will be selected from interviews with neighboring property owners, tenants, and other knowledgeable people, such as members of the local historical society. The sampling network will consist of at least two activated carbon samplers placed at stream road crossings and at any springs large enough to likely receive waters from the site (by placing two samplers at each location, duplicates will be collected for quality control purposes; additionally, the second sampler insures a backup if a sampler is damaged, lost, or stolen). Any springs not directly sampled will be indirectly sampled at downstream sampling stations. The actual stream station plan will be determined after the interviews and inspection are performed. However, based on published information as well as a current understanding of the area, a network of four control and 23 dye sampling points are shown on Figure 3.

Control point stations will also be established at streams near the site. These stations will be sampled to detect possible extraneous fluorescent compounds. These background and control data will provide limits on ambient conditions that could interfere with the interpretation of tracer results.

The coordinates for all selected stream sample stations will be determined in the field with a hand held GPS device. These data will be downloaded to Tradition's Access database established using US, Illinois, State Plane NAD83, Illinois West, U.S. feet coordinate system. This database interfaces with a GIS platform (ArcGIS 9.3.1) that will allow determination of the distance from each station to the basins. Following establishment of the network, these data will be exported to a table that will include the station coordinates, distance to the basins, observed approximate discharge (for identified springs) and other pertinent observations made during the field inspection. The table will then be submitted to USEPA for comment.[4]

Two background sampling events will be performed. The first round of water and carbon samples will be analyzed prior to selecting the dye type and quantity, and the subsequent background sampling event will be analyzed concurrent with dye introduction. All background samples will be analyzed and used to interpret the dye tracing data.[5]

4.3 Man Made Voids Study/ Drilling and Packer Testing

The data developed during the geophysical survey will be evaluated and in consultation with the geophysicist, proposed drill locations will be selected. These selected drill sites and the rationale for each will be submitted to USEPA for review and discussion in a conference call to be convened within one week of submittal. Although the actual number and position of the drill sites will be determined, for planning purposes a minimum of six sites within the geophysical

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[4] All springs that discharge from bedrock within the comprehensive surface sampling network shown on Figure 3 of the work plan will be identified. If a bedrock spring is considered not relevant to the investigation, the justification for that opinion will be described to USEPA. With the Agency's concurrence, the subject spring will be eliminated from the sampling network. As shown on the project schedule, the first of two background sampling events will be performed upon establishment of the sampling station network. If the Agency believes that any spring identified as not relevant should be reconsidered for sampling, USEPA is requested to contact the Tradition field staff before completion of the initial sampling event.

[5] It can take one to two weeks for the laboratory turnaround from the date of field collection. As shown on the attached schedule, the second background sampling event will be collected beginning one week following completion of the first event. Carbon samplers will be placed immediately following collection of the first background sample. This will allow the second sample to be collected before the introduction of dye. Accordingly, fresh samplers will be re-established immediately prior to dye introduction to ensure that any fluorescence can be properly attributed to the post-dye introduction time period. Although the final round of background samplers will not be analyzed prior to dye introduction, this procedure follows the proper field methodology.

study area will be selected. A conceptual layout of six drill sites within the basin area is shown on Figure 4.

Two borings will be advanced at each drill location. One will be drilled to the top of bedrock using 6¼-inch inner diameter (ID) hollow stem augers (HSAs). At auger refusal a temporary PVC two-inch diameter well screen and riser will be installed. This well will be constructed as a water table well with the appropriate screen length (up to 15' as necessary) intersecting the water table. A pressure transducer will be placed in the temporary well to monitor water levels.

The second boring will be drilled adjacent to the first also using 6¼-inch ID HSAs. At auger refusal a temporary four-inch ID steel casing will be advanced within the HSAs using air rotary methods. This casing will be seated within the bedrock a short distance (several inches to one-foot), and then sealed with bentonite along the outside of the casing as the augers are retracted. Following auger removal a 3½-inch outer diameter (OD) core barrel will be advanced through the steel casing into the bedrock using air rotary supply methods. The core barrel will be advanced in five- or ten-foot runs. Each run will be properly logged by a qualified geologist and catalogued for type, rock characteristics, fracture occurrence and frequency, rock quality designation and percent recovery. Each bedrock boring will be cored to a target depth sufficient to evaluate karst conditions in the vicinity of the basins. This depth will be determined by the geophysics and drilling conditions encountered, but a nominal elevation of 935' msl is assumed (The 935' elevation is the minimum previously investigated at the site; this depth compares to 971' top of bedrock elevation at the northwest corner of the north pond, to 956' top of bedrock elevation south of the south pond at the head of the tile-fed drainage ditch). When coring is complete the packer will be placed at a depth below the temporary casing based on the results of the coring lithology.

After the packer is inflated, a pressure transducer will be placed above the packer. Two types of tests will be conducted through the packers. The first will be a traditional packer test with three increasing steps followed by two decreasing pressure steps. Each step will have its pressure and cumulative water flow recorded at one minute intervals. When three consecutive, equal (steady state) measurements are recorded during each pressure application), the test will progress to the next step. If the appropriate response is observed during the pressure measurements such as discussed in Section 5.0 in the attached (Royle), then a second packer test will be performed as described below.

Water will then be added to and pressure maintained in the boring through the packer for a minimum of three hours or until 500 gallons of water has been introduced into the bedrock to determine whether or not the boring meets the criteria for dye introduction.[6]

No packer test will be performed with applied pressures exceeding the calculated total lithostatic pressure to prevent hydrofracturing of the bedrock. The pressure transducer at the subject

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[6] Tradition recommends that there should be no more than a 24-hour delay between packer testing and dye introduction. If no borehole meets the minimum criteria, the attached schedule shows a contingency of one additional week to allow USEPA review of the packer test data prior to borehole abandonment.

borehole and the pressure transducer at the adjacent temporary well in the overburden will be monitored during the test for increases in pressure that will indicate short circuiting of flow around the packer. If short circuiting is measured, the packer will be lowered and the test repeated until the baseline pressure above the packer or the adjacent overburden well is not increased.

During the drilling program daily water levels will be collected at each temporary well/ bedrock borehole pair following removal of the packer equipment. These data will confirm the extent of the water table aquifer in the basin study area and if any perched or confined aquifer conditions are present. At the conclusion of the final packer test, the horizontal coordinates (in accordance with the Illinois State Plane coordinate system) and top of casing elevations at the bedrock borings and temporary wells will be surveyed. Following completion of the dye introduction program, the temporary wells and bedrock borings will be properly abandoned.[7]

4.4 Tracer Test

Prior to establishing the sampling network, pH, temperature, and specific conductivity will be measured at nearby springs (as practical) and at field tile discharge points as references. These data will be recorded in a field log book. These parameters will also be measured and recorded at the background sampling stations. These parameters will be measured at any springs included in the sampling network along with their estimated discharge. Discharge will be estimated by estimating average velocity, overall channel width, and average depth. All sampling locations will be photographed and recorded with a GPS device.

Primary reliance will be placed on activated carbon samplers because they sample continuously and accumulate dye. These samplers essentially lower the practical detection limit for any given dye. Grab samples of water at stream stations will also be collected at each location whenever a sampler is placed or replaced. These grab samples will only be analyzed if there is no carbon sampler, if there is dye in the associated charcoal sampler, or at the discretion of the field geologist. Grab samples can act as confirmation samples and will be the only samples in the chain of custody at all times. However, it is common for water samples to be nondetect for dye, when the carbon sampler yields a detection as it has accumulated dye since placement.

A sampling network will be established for the detection of dye. While it is likely that flow will remain within the topographic basin, the sampling network will be sufficiently comprehensive to detect dye in the event of interbasin transfer in any direction.

The network shown on Figure 3 is preliminary. Some upstream reaches may be dry and may be impractical. The stations shown at Spring Creek, several miles to the east, are only included

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[7] Abandonment procedures will be performed in accordance with Illinois Administrative Code Title 77, Chapter I, Subchapter r, Part 920, Section 920.120. In accordance with these regulations, a neat cement slurry mixture (5 gallons of water per 94 lb bag of cement that can include up to five percent bentonite) will be delivered via tremie pipe and the boring filled to the ground surface. For the overburden monitoring wells, the well casings will be properly removed and the borings abandoned using the same method as that for the bedrock borings.

because of the name. If the presumptive springs that are the cause of the name of this creek are small, these sampling stations will likely be eliminated.

Two rounds of background sampling lasting approximately one week each will be collected prior to borehole dye introduction. At least one round of background samples including both carbon and water samples will be analyzed prior to dye introduction. Because the area is rural, significant interference from background fluorescence is not anticipated.

Dye type and quantity will be based on the results of the first round of water and carbon background analysis as well as the longest distance to a sampling station. However, it is anticipated that the dye selected will be either fluorescein, eosine, or rhodamine WT. Sufficient dye will be used to achieve a detection that is at least 10 times background (if any) at the most distant sampling station. The dye will be introduced prior to demobilizing the packer testing equipment if any of the borings exceed the threshold criteria for dye injection upon analysis of the packer test results (Section 4.3). If one boring transmits significantly more water than the others, that boring will be selected for dye introduction. If there are multiple borings that meet or exceed the minimum criteria and have similar ability to transmit water into the bedrock, each will be used as a dye introduction point. The same dye will be introduced at each dye introduction point if multiple dye introduction points are used. The dye will be flushed with a minimum of 2,500 gallons of potable water. The flushing water will move the dye out of the boring and into conduits with natural flow thus expediting the trace.

Sampling will be on a schedule of decreasing frequency. The purpose of the schedule is to provide reasonable time of travel data. An initial sample will be collected one day after dye introduction, followed by a second sample two days after dye introduction, a third sample four days after dye introduction, a sample seven days after dye introduction, and then weekly samples for six weeks. Beginning at seven weeks after dye introduction, samples will be collected approximately every other week until termination. Termination of sampling will be determined by the longest straight line distance to a sampling station divided by 50 feet per day.[8]

Sample collection will be documented in a field log book along with digital photographs. The date, time, and sampling station name and number will be recorded on the outside of the sample containers. The water sample will be collected in a disposable vial and the activated carbon placed in a Whirl-Pak® bag. Samples will then be chilled immediately to approximately 4° C until analysis. The collection data will be recorded on a data collection sheet provided by the laboratory (see Figure 5). Samples will be shipped overnight (chilled with blue ice in a cooler) to a laboratory for fluorescence analysis using a scanning spectrofluorophotometer. A laboratory that specializes in fluorescence analysis for dye tracing such as Ewers Water Consultants, Inc. will be used.

Detections must meet the laboratory's criteria for dye and must be at least 10 times any background fluorescence for that dye. Background fluorescence sampling will be performed at

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[8] The minimum velocity at which Tradition's tracer subcontractor (Philip Moss) successfully performed a test in karst geology.

all locations during the background period and at control points after dye introduction.

Laboratory detection and reporting limits are typically less than 0.1 ppb for all of the dyes being considered.

If dye is credibly detected at a sampling point, a thorough search of that stream reach will be bracketed by a detection-non detection pair of samples for the spring or springs that discharged the dye. If a complete dye trace is successful, it is likely that the dye will discharge for more than a few days. A visual search will be performed of the discharge area and include measurements for pH, temperature, and specific conductivity. If necessary, a field fluorometer will be used to locate the relevant spring or springs (although field fluorometers can produce false positives, a detection will have been made by a laboratory using a scanning spectrofluorophotometer). If there is a positive detection in water, a field fluorometer will be used to detect fluorescence in water consistent with the dye from the downstream detection point to its upstream point of discharge. If there is no detection in the associated water sample, but only in the activated carbon sample, then no attempt will be made with a field fluorometer; reliance will be placed on visual observations and measurements of pH, temperature, and specific conductivity. If necessary, seepage runs will be conducted as well. Seepage runs are a series of stream flow measurements typically made with Pygmy current meters or similar devices at measured cross sections. A series of carefully measured stream discharges over a stream reach can identify gains or losses that are in excess of the method measurement error.

4.5 Report Preparation

The results of the above field studies will be compiled in a report presenting the findings and conclusions of the investigations. The report will be submitted to USEPA no later than 45 days of completion of the field studies.

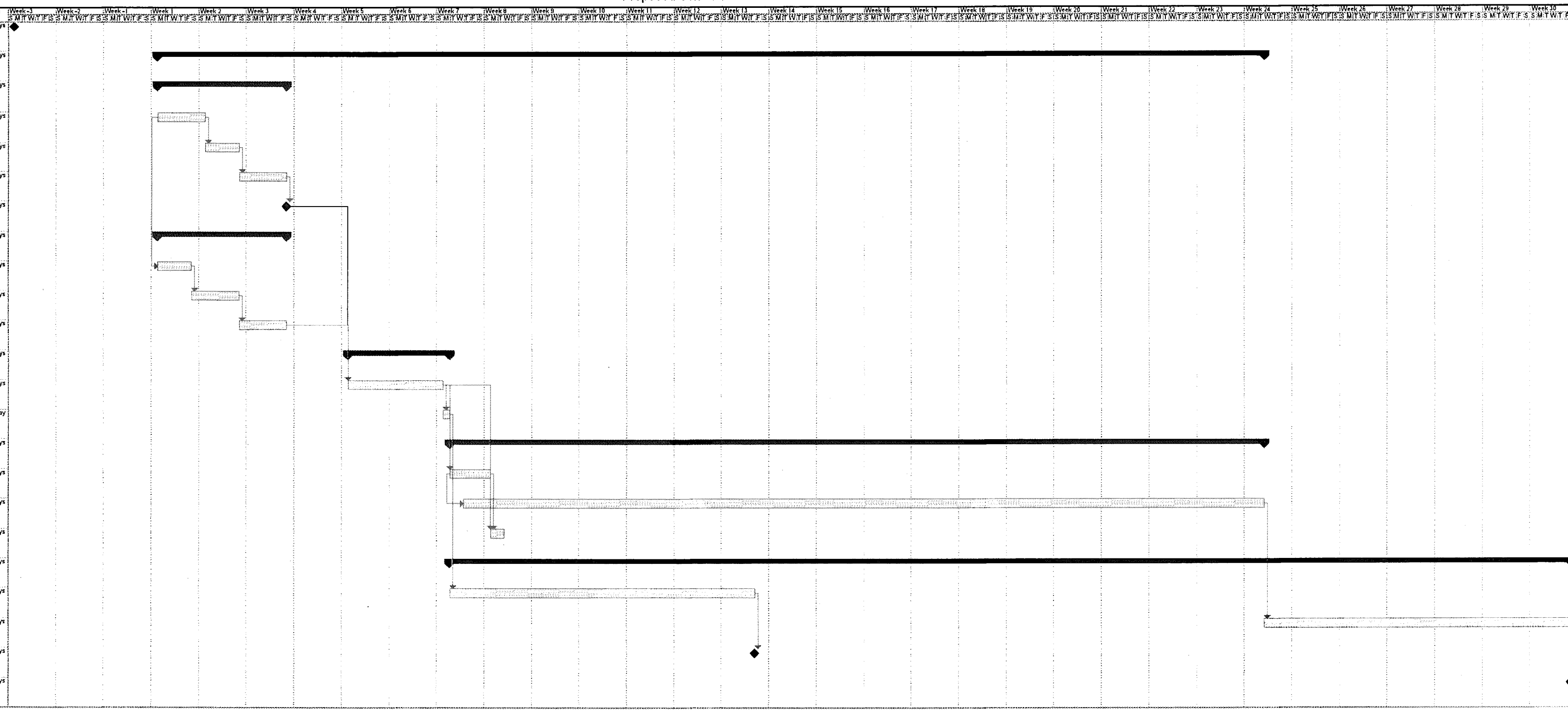
5.0 Project Schedule

The geophysical investigation is anticipated to require one week for field data collection, followed by five days of data interpretation. Within this time frame, the stream sampling network will be established and the two background sample events performed. Candidate borehole locations will be selected following receipt of the geophysical results, and then submitted to the Agency for review and consideration as provided herein. Within one week of submittal, the Agency and Tradition South will confirm the final site locations. The drilling equipment will then be mobilized as soon as the schedule permits (assumed to be within one week of finalizing locations). The drilling program and packer test program is anticipated to require 10 to 14 days. If tracer test monitoring is performed, it is anticipated to require a maximum of 17 weeks from dye introduction.

The proposed project schedule in the form of a Gantt chart is attached on the following page. This chart assumes the field program will begin within two weeks of work plan approval. It includes the various task durations linked as appropriate in accordance with the task descriptions previously described. It also shows separate timelines for completion of field activities along with the subsequent report with and without tracer tests.

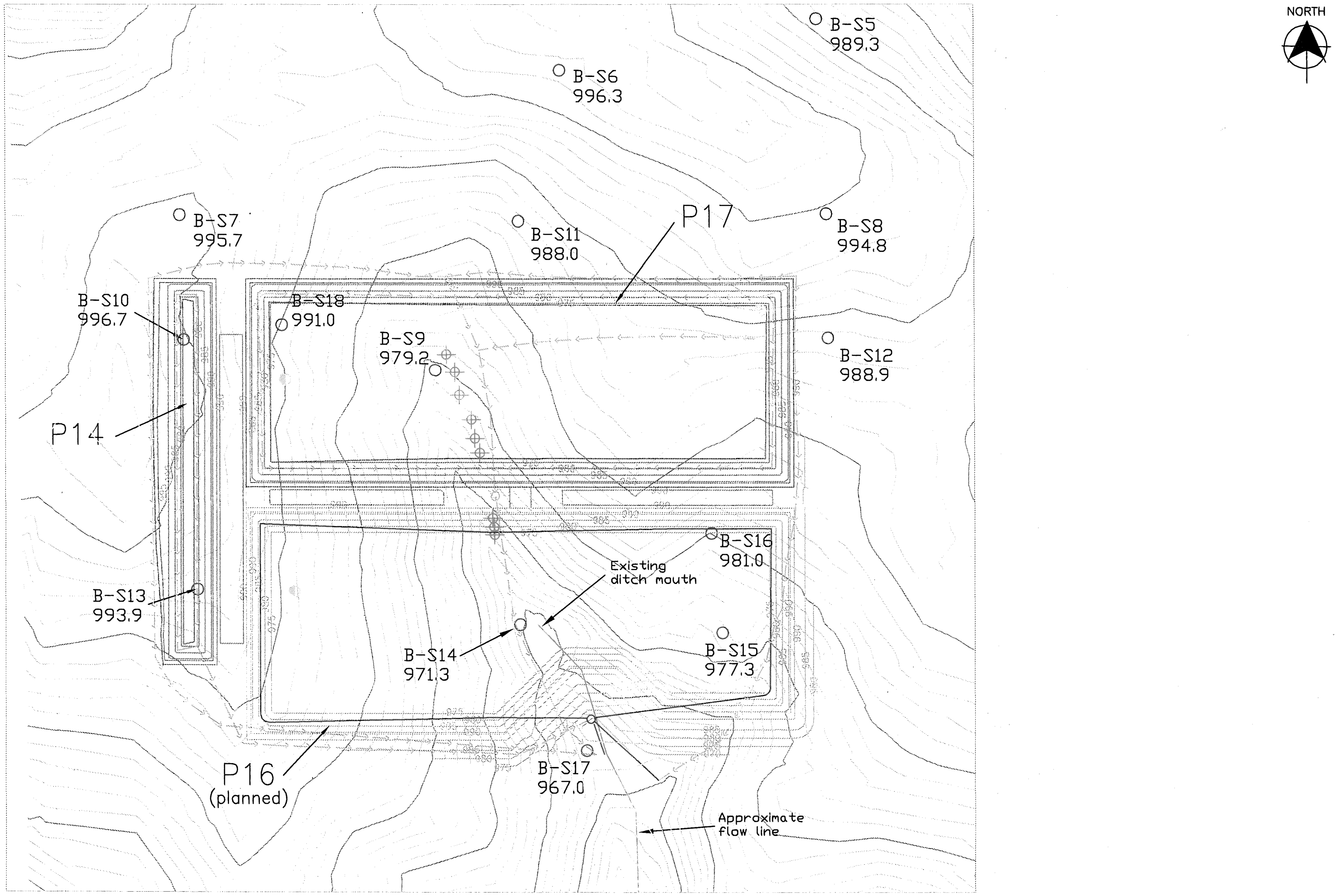
§ 308 CWA Request Investigation
Tradition South Dairy
Proposed Schedule

ID	Task Name	Duration
1	Work Plan Approval	0 days
2	Field Program (Extended)	163 days
3	Geophysical Investigation	19 days
4	Data Collection	7 days
5	Data Interpretation	5 days
6	USEPA review	7 days
7	USEPA/ Tradition conference call	0 days
8	Background Stream Study	19 days
9	Area Inspection/ Establish Station Network	5 days
10	Background Round 1	7 days
11	Background Round 2	7 days
12	Drilling Program	15 days
13	Drilling/ Packer Tests	14 days
14	Survey Boring Locations	1 day
15	Tracer Tests	120 days
16	Dye Introduction	6 days
17	Tracer Dye Sampling	118 days
18	Borehole Abandonment (w/ or w/o Tracer Tests)	2 days
19	Report (Extended)	165 days
20	w/o Tracer Tests	45 days
21	w/ Tracer Tests	45 days
22	Report Submittal w/o Tracer Tests	0 days
23	Report Submittal w/ Tracer tests	0 days



Project: Tradition South Dairy - Karst I
Date: July 21, 2011

Task | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Milestone | Rolled Up Progress | Split | External Tasks | Project Summary | Group By Summary | Deadline



HORIZONTAL SCALE: 1" = 250'

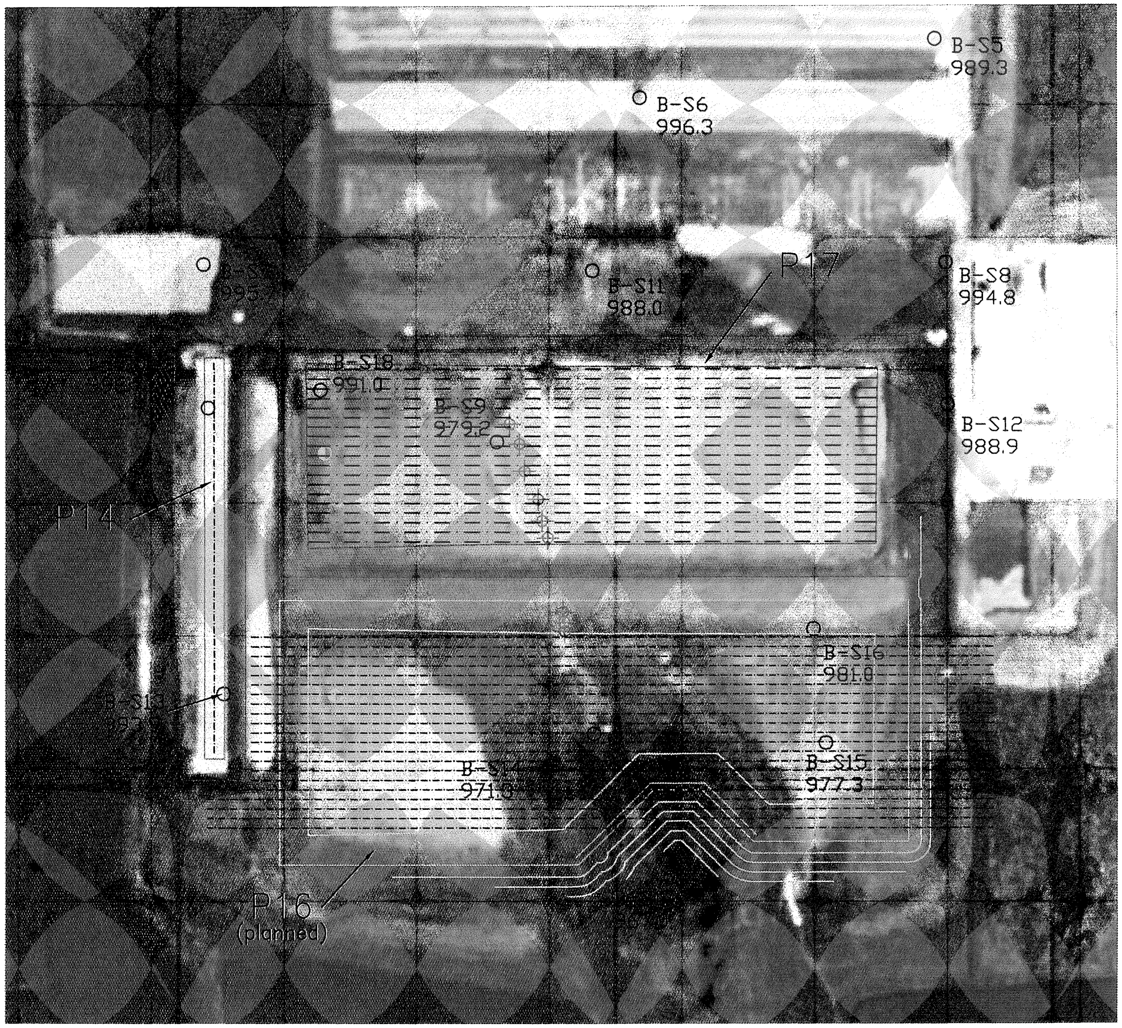
LEGEND

- SOIL BORING WITH SURFACE ELEVATION (ADVANCED PRIOR TO BASIN CONSTRUCTION)
- TEST PIT (ADVANCED DURING BASIN CONSTRUCTION)
- BEDROCK SOIL PROBE (ADVANCED DURING BASIN CONSTRUCTION)
- AS-BUILT SURSURFACE DRAIN TILE
- BASIN P16 SURFACE DRAIN TILE (NOT YET CONSTRUCTED)

FIGURE 1
BASE MAP WITH PREVIOUS SUBSURFACE BORING LOCATIONS
Tradition South Dairy, Nora, Illinois

NOTES:
BASINS P14 & P17 HAVE BEEN PARTIALLY CONSTRUCTED, BASIN P16 HAS NOT YET BEEN CONSTRUCTED.

DRAIN TILE SYSTEM HAS BEEN CONSTRUCTED AROUND BASINS P14 & P17 AND DOWN THE CENTER AND AROUND THE PERIMETER OF ALL PLANNED BASINS. DRAIN TILES ARE NOT INSTALLED AROUND SOUTH END OF PLANNED BASIN P16.



NORTH

HORIZONTAL SCALE: 1" = 250'

LEGEND

- ○ SOIL BORING WITH SURFACE ELEVATION (ADVANCED PRIOR TO BASIN CONSTRUCTION)
- TEST PIT (ADVANCED DURING BASIN CONSTRUCTION)
- BEDROCK SOIL PROBE (ADVANCED DURING BASIN CONSTRUCTION)
- —·—·— CCR GEOPHYSICAL SURVEY TRANSECTS (20 FOOT SPACING)
- — — EM GEOPHYSICAL SURVEY TRANSECTS (20 FOOT SPACING)

FIGURE 2
PROPOSED GEOPHYSICAL SURVEY TRANSECT LOCATIONS
Tradition South Dairy, Nora, Illinois

NOTES:
BASINS P14 & P17 HAVE BEEN PARTIALLY CONSTRUCTED, BASIN P16 HAS NOT YET BEEN CONSTRUCTED.

BASE MAP SOURCE: GOOGLE EARTH 2009 IMAGE

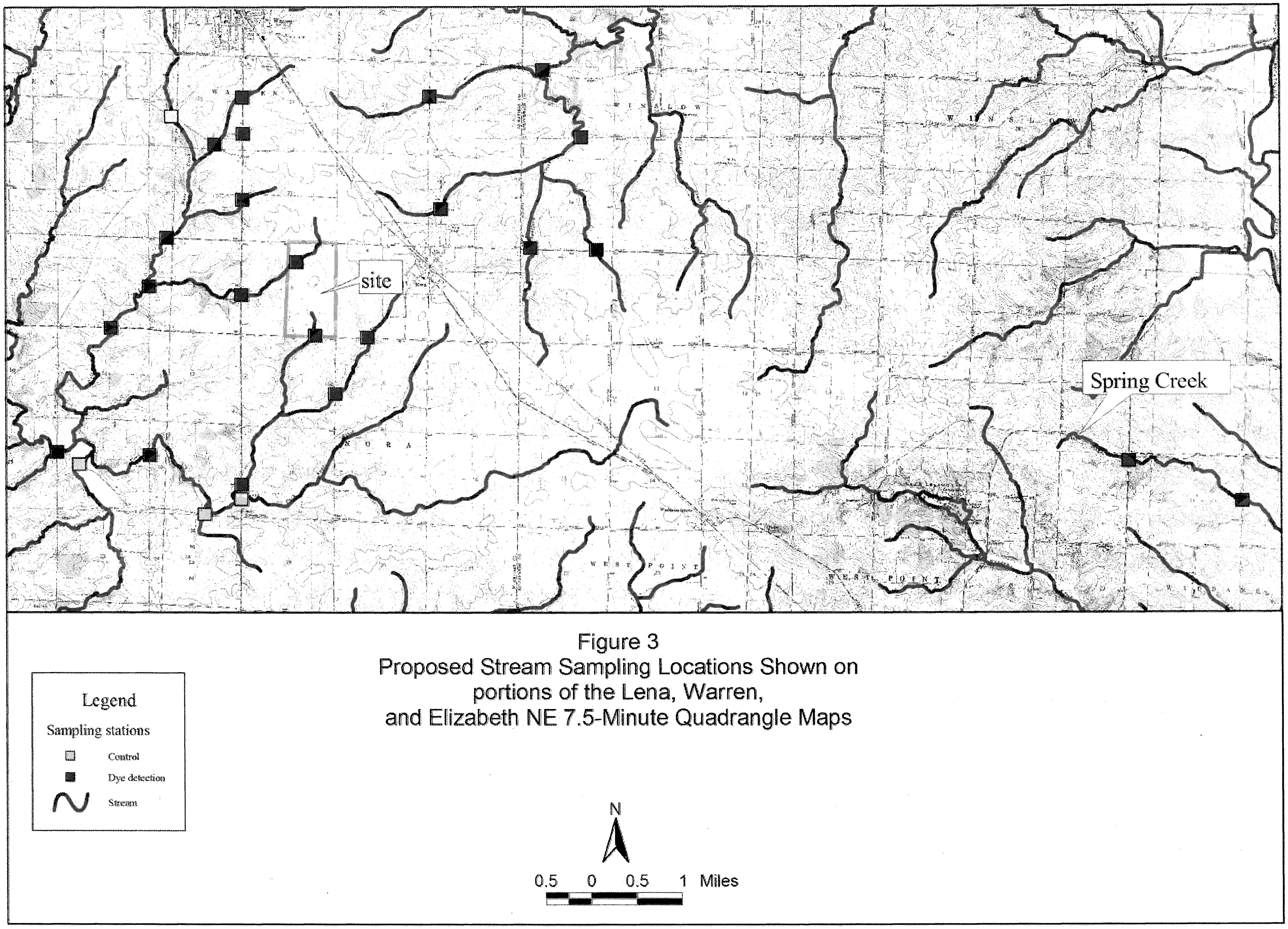


Figure 3
Proposed Stream Sampling Locations Shown on
portions of the Lena, Warren,
and Elizabeth NE 7.5-Minute Quadrangle Maps

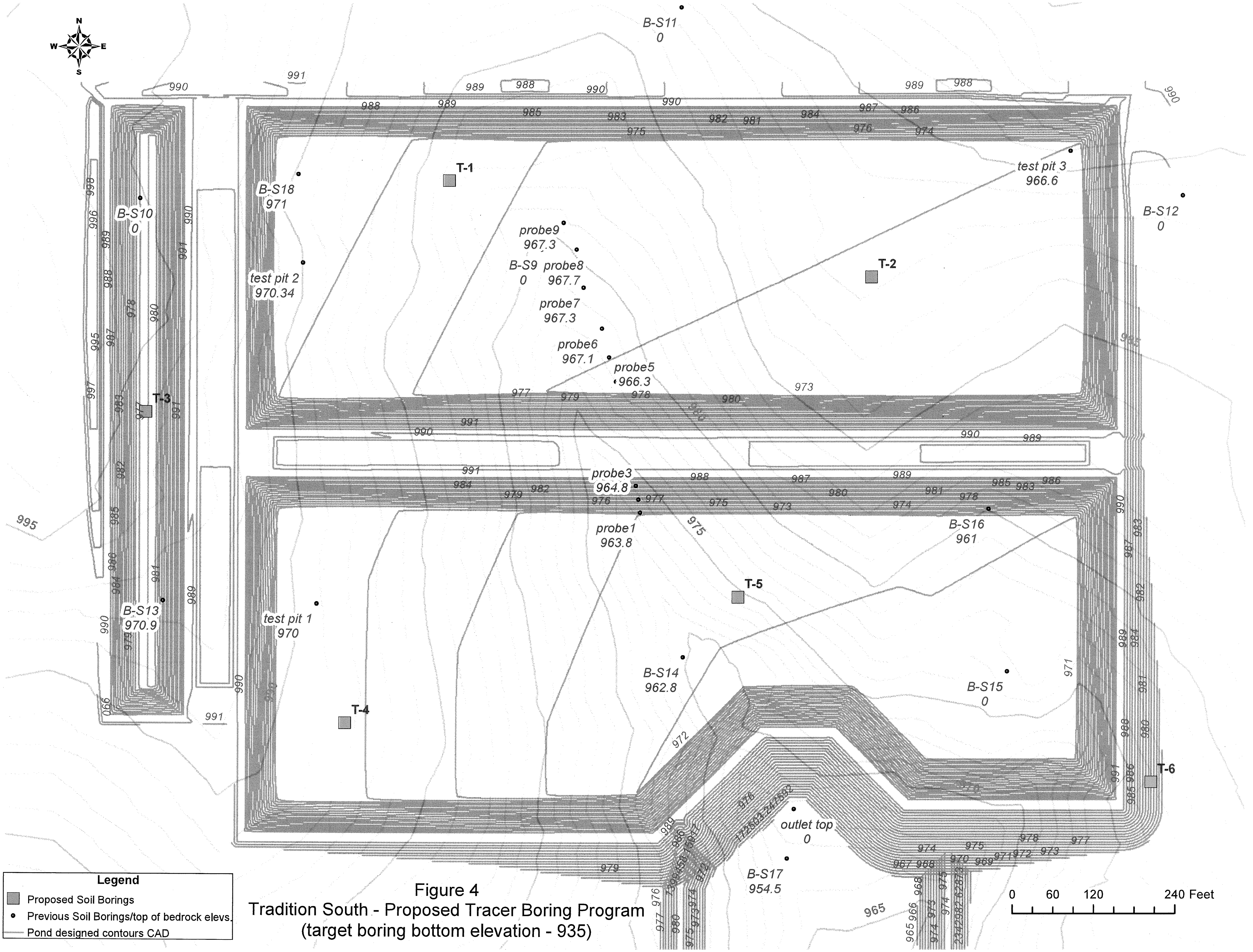


Figure 4
Tradition South - Proposed Tracer Boring Program
(target boring bottom elevation - 935)

Custody Transfer Record - Analysis Request

Client: ____UVA Wise______________________
Project:___The Cedars______ ______________
Date: ______________________

EWC **Ewers Water Consultants Inc.**
160 Redwood Drive
Richmond, KY 40475
ewc@mis.net

ID Number	Description	Date Set	Date Collected	Time	Matrix	Analyses Requested	Observations

Relinquished By	Received By	Date	Time	CODES
				Matrix = W-Water, C-Charcoal, FER= Fluorescein, Eosin, Rhodamine WT, and Sulpho-Rhodamine B ODY= Optical Brightener, Direct Yellow P = Pyranine O = Other

Figure 5.
Example Custody Form

STANDARD OPERATING PROCEDURES FOR BOREHOLE PACKER TESTING

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STANDARD OPERATING PROCEDURES
FOR
BOREHOLE PACKER TESTING

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STANDARD OPERATING PROCEDURE
FOR
BOREHOLE PACKER TESTING

1.0 INTRODUCTION

1.1 Scope of Document

This document is to outline various common procedures for operating a wireline packer testing assembly. The document covers the general operating procedures, testing methods, and basic troubleshooting. It is imperative, however, that the tester has sufficient experience working with wireline drilling equipment in order to be able to visualize what is happening during tests and, especially, if problems arise. Numerous difficulties can arise during the drilling and testing process, and so the user is cautioned to make sure they are aware of both the complexity and the potential risks (safety and cost) that can be incurred carrying out these tests.

Furthermore, it is stressed that the operation of the packer system can be hazardous if carried out by inexperienced staff, and therefore proper training and supervision must be carried out for all personnel involved. This is especially true for staff without previous drilling experience.

The final section of the document has a brief discussion of data analysis. However, as this is a very involved topic, we have not included anything more than what is needed to make an appropriate and meaningful interpretation of the data collected.

1.2 Reasons for Packer Testing

Packer tests are carried out to assess the variability of a borehole as it intersects various hydrogeological units. Open hole water levels and pumping tests can give misleading results in such environments. Therefore, packer testing is often utilized to help understand the detailed hydrogeological properties of the various horizons. This knowledge can often be essential to the proper design of the hydrogeological program.

1.3 Types of Test Apparatus

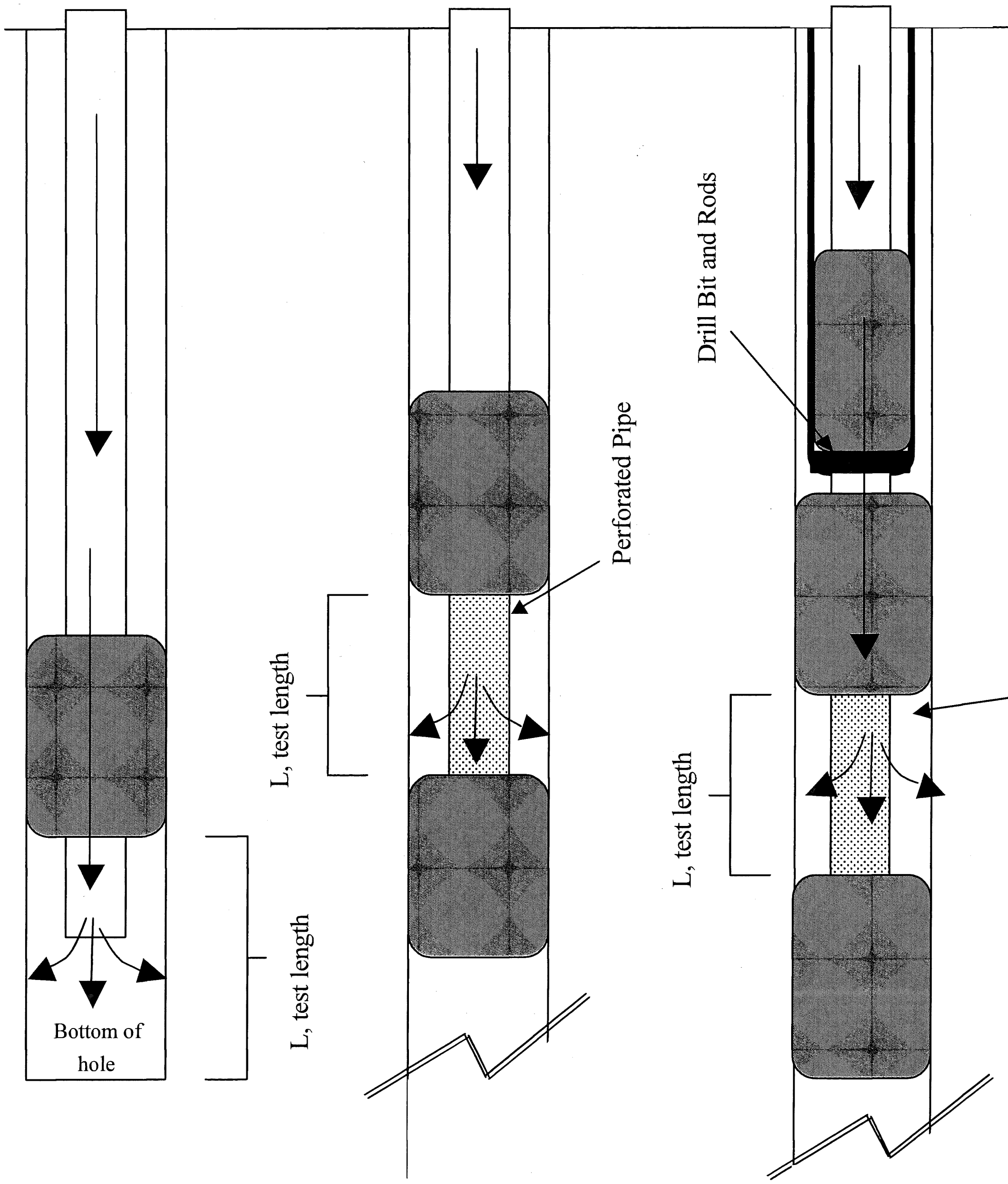
Packer testing is carried out in either open boreholes or through the wireline drilling rods. The latter situation allows for the packer equipment to be used in unstable boreholes where unstable wall rock conditions would likely cause the tool to become jammed by falling rock or sand. It also allows for the drill rods to be used as the test water supply line, thus making it far easier to deal with the equipment involved in deep testing scenarios.

The packer assemblies used in open boreholes and through wireline rods have different configurations. The two types of test apparatus (see Figure 1) are referred to as:

a) Single Packer tests (Figure 1A); and
b) Double or straddle packer tests (Figures 1B and 1C).

Both types of tests are carried out in open boreholes and through the wireline drill rods as illustrated.

FIGURE 1: Packer Test Assemblies



1A:Single Packer Test, Open Borehole

1B: Double Packer Test Open Borehole

1C: Double Packer Test, Wireline Assembly

1.4 Types of Tests

Packer tests consist of measuring the rate of flow and/or pressure build-up/decay in the test interval over a period of time. The upper range of hydraulic conductivity that can be measured using packer systems will be limited by the hydraulics of the injection system (rate and pressure output limit of pump, supply line (friction losses), water availability, etc.). Therefore, it is important to determine before finalising equipment what the expected testing range of the zones of interest will be, before starting the testing program.

1.4.1 Injection (Lujeon) Tests

Injection testing methods, otherwise know as Lujeon tests, are carried out in drillholes with static water levels below ground surface. Water is injected at specific pressure "steps" and the resulting pressure is recorded when the flow has reached a quasi-steady state condition.

The steps are used to "ramp" up and down through the expected pressure range. The behaviour of the system to the increasing and recovery injection can render useful information on the rock and fracture behaviour, as well as packer and injection performance. This is discussed further below in Section 5.

1.4.2 Discharge Tests

Discharge tests are carried out in drillholes with flowing artesian conditions. In these drillholes, the natural formation pressure response is monitored after the equilibrated shut-in is allowed to decay with respect to time. The data are plotted logarithmically and analysed using standard Jacob straight line techniques. This will be discussed further below in Section 5.

1.4.3 Shut-In Recovery Tests

Shut-In recovery tests are usually run immediately following a Discharge Test. The shut-in pressure build-up over time is monitored and plotted against log10(t/t'), where t is the time elapsed since the start of the discharge test, and t' is the time since the recovery test was started. This is explained in more detail in Section 5 below.

2.0 EQUIPMENT REQUIRED

The general list of equipment required for carrying out wireline packer testing is given below for an HQ sized wireline system. Any equipment listed as HQ will need to be duplicated as PQ or NQ if using different sized systems. Note that most of the actual packer assembly components are usually made of stainless steel.

Recommended list
(Note: this list may not be fully inclusive and should only be used as a guide)

1) HQ size wireline straddle packer unit (2 complete units);
2) Spare HQ sized glands (2);
3) Spare o-rings for unit;
4) HQ sized stuffing box;
5) Spare o-rings for stuffing box
6) HQ sized seating cone;
7) Lifting bail and top supply tube for packer assembly;
8) Pipe couplings for connecting packer assembly (with spares);
9) Packer End cap (for blocking flow through bottom of straddle packers)
10) Double packer set-up will require 1.5m, perforated spacers (5) and 3.0m, perforated spacers (2) in order to test variable length intervals;
11) Dampened gauges able to measure L/s or m^3 to within 5% accuracy;
12) Pump capable of up to 3.75 L/s (50 Igpm) at 120 psi (flow rate and pressure specified may be greater if testing in high permeability environments);
13) Require minimum of 2 spares for all glands, gauges, regulators, and meters;
14) Regulator (if using gas) or hydraulic packer inflation pump (if using water) and all lines and fittings, capable of maintaining 2000 psi or 500psi pressure respectively;
15) Composite inflation line and support cable;
16) Reel (motorized if tests planned for greater than 200 m in depth);
17) Lifting Sheave or Pulley block for running composite cable through (to be equipped with cable counter if possible).

In addition, equipment must be tested prior to starting program. The following testing criteria are recommended

1) All inflation equipment must be pressure tested to 2000 psi (for pneumatic systems) or 500psi pressure (for hydraulic systems);
2) All packers must be tested to maximum design pressure;
3) Require ability to calibrate friction losses in pumping system and packer system prior to testing;
4) Will need to have bypass valves installed before and after the pressure gauge/flow meter assembly in order to control pressure/flow and to protect flow meter from back-pressure;
5) Pressure gauges should be calibrated if possible (plumbing in spare gauges and comparing measurements may be only means available on site); and
6) Flow gauges should be calibrated using a container of known volume (should exceed 100 L)

3.0 PACKER INFLATION

When packers are inflated downhole, the inflation line pressure is a combination of the pressure required to:

- stretch the packer gland to where it will contact the drillhole wall;
- overcome the hydrostatic pressure (ie: pressure exerted by the overlying water column), and
- inflate it to the working pressure (dependent on the gland).

The inflation pressure will therefore change based on the equipment used and the height of the overlying column of water above the packer. The various aspects of the inflation pressure determination are discussed below.

3.1 Hydraulic vs. Pneumatic - overcoming hydrostatic head

Packers are commonly inflated with compressed gas. Generally, an inert gas such as nitrogen is used for safety reasons (ie: risk of ignition). A disadvantage of compressed gas in deep testing applications is the inherent safety concern of bursting inflation lines or fittings at surface (ie: in close proximity to testing crew) due to the high working pressures required.

Alternatively, for deeper applications, water or hydraulic fluid/antifreeze can be used to inflate the packers. The advantage is that water is essentially inelastic, and so burst lines do not have the same degree of stored potential energy that an elastic gas filled line does. Therefore, burst hydraulic lines pose a lower risk than pneumatic lines. A further advantage to a hydraulic (water) system in deep test situations in that the natural hydrostatic pressure of the water in the inflation line will equal, or exceed (if static water level is below ground surface), that of the adjacent water in the formation, and therefore, the only pressure required is to inflate the packer itself.

It should be noted that both pneumatic and water inflated systems are prone to freezing in cold conditions. Antifreeze or hydraulic fluid can be used to overcome this problem, but may pose an unacceptable environmental risk. Brine solutions can also be used to reduce freezing susceptibility, but this can cause corrosion issues that are just as problematic. Inflation fluids must be assessed for compatibility with the packer gland material as well.

Use of antifreeze or brine solutions could also affect permeability results if interactions with clay gouge in open fractures causes these materials to swell, thus reducing the apparent permeability of the rock being tested. This can be assessed by inspecting gouge material in the rock core and carrying out surface tests with the expected test fluid.

3.2 Packer Inflation Pressure

The testing unit packers must be inflated to the working pressure to ensure a proper seal. This pressure is normally in the range of 250 psi. As mentioned above, when the packers are inflated downhole, allowances for the hydrostatic pressure (pressure from overlying water column) must also be accounted for.

If the water column is assumed to be approximately 1.4 psi/m of water (based on density of fresh water), then the inflation pressure (gauge pressure at surface) required will be:

$$P_i = P_w + H_{wc} \text{ x } 1.4 \text{ psi/m}$$

Where:

P_i = packer inflation pressure
P_w = packer working pressure
H_{wc} = Height (vertical) of water column above packer (adjust for angled holes)

It is important to note that in a drillhole with water levels close to, or at surface, such as in a flowing artesian hole, the water column in the inflation line and in the drillhole will be essentially equal; therefore Hwc will be approximately equal to 0 m. This is not the case for pneumatically inflated packers, which require extremely high inflation line pressures, presenting a significant safety and gas usage problem. (Note: in a flowing artesian hole and a 750 m deep test zone, the hydrostatic pressure would be approximately 1050 psi. This inflation line pressure would then need to be increased to approximately 1250 psi to inflate the packers to the required working pressure.).

3.3 Hydraulic vs. Compressed Gas Inflation in Deep Drillholes

3.3.1 Hydraulic Packers - Single vs. Dual Inflate/Deflate Line

In a packer system equipped with hydraulically inflated packers, it is common to have a dual inflate/deflate line. This apparatus allow for water to be pumped down one line when inflating the packer, and allows water to be returned up the second line when deflating the packers. The packer gland, and both the inflate and the deflate line, can also be evacuated using compressed gas to push the water out.

However, for very deep testing systems, the dual inflate/deflate line is prohibitively expensive and bulky. Therefore, a single line cable system is used. This then requires that the single line acts as both the inflation line and the deflation line. For a compressed gas system this does not pose a problem. However, for a hydraulic system, the water in the line can cause unwanted packer inflation as the equipment is lowered and raised in the un-submerged portion of the drillhole if the water level is significantly below ground surface (i.e.: causes enough hydrostatic head in the inflation line to cause flow into the packer gland.)

The water capacity of the inflation line will be of limited capacity, and therefore, will not supply significant inflation fluid. However, it can be enough to distort the packer gland if the depth to water is significant. If water levels are more than 25m below ground surface, the hydraulic packer system should be equipped with an inflation activation valve as part of the inflation line that prevents inflation when lowering the tool into a drillhole where the water level is below ground surface (otherwise hydrostatic level in inflation line would begin to inflate the packers). To prevent this, the pressure valve is set to a predetermined opening pressure (i.e.: 100 psi; equal to ~70m of hydrostatic head) to compensate.

Alternately, it is possible to use compressed gas. However, "pressure compensation" will likely be required in deep tests as the gas filled gland can distort due to the hydrostatic pressure during tripping in and out of the drillhole. This procedure will require that the packer glands to be pressurized during lowering, and depressurised during raising, to compensate for the applied hydrostatic pressure. The line pressure used will be dependent on the hydrostatic pressure (overlying water column height) and will, therefore, need to be calculated based on drillhole conditions, and depth of test, and tested by trial and error. Great care must be taken in the initial tripping in and out as incorrect pressures could cause the tool to jam. This could damage the gland and/or the cable and reel system.

4.0 PACKER TEST – PREPARATION

This section has been written for wireline, hydraulically inflated packer systems, but is similar to pneumatic system operation. Greater care must be taken with pneumatically inflated packers systems; however, due to the elastic energy in the compressed gas and the potential for explosive release if airlines, etc. burst, especially when working in deep drillholes where high operating pressures are required.

The basic steps for preparing for a packer test are outlined below. It is important to make a systematic

1) Prepare packer assembly: two packers with open bottom for single test or three packers with perforated middle pipe section and closed cap on the bottom for straddle packer test (see figure 1);
2) Check inflation line connecting the packers and fittings – do not over tighten as you might strip the threads;
3) Check packer assembly for any leakage. Inflate to maximum gland working pressure in appropriate length and diameter of drill casing or drilling rods;
4) Check wire line connectors on packer assembly and stuffing box components (especially seals);
5) Prepare and check water feeding system: tank, supply, pump, connection hoses, pressure gauges, valves and flow-meter;
6) Design test parameters: depth and length of tested zone, drilling bit depth (double check drillers count of rods in drillhole), position of packers, inflation pressure and water pressure for three stages
7) Drill hole preparation: removal of drilling mud and cuttings (flush with clear water);
8) Pull rods up to locate drill bit at selected depth;
9) Prepare wire line winch;
10) Install stuffing box on drill rods;
11) Measure groundwater level prior to installing packer system several times to assess static groundwater level (or measure pressure, if flowing artesian, once packer assembly and stuffing box are installed);
12) Lift the packer assembly using the wireline and lower to landing ring at drill bit– check if seats on landing ring by "listening" to rods using wrench, etc. If possible, check depth marking on wire line if this has been marked for the expected depth;
13) If hole is flowing artesian, install stuffing box seals around wireline and inflation lines – if not, go to step 15;
14) Measure shut-in pressure if hole is flowing artesian;

15) Inflate packer slowly (by 50 psi steps) until working pressure has been reached. This will require filling to working pressure plus calculated hydrostatic pressure (see below for calculation);
16) After inflation is complete, monitor packer inflation line pressure for 2 minutes minimum to see if system is leaking. If no leaks apparent, then;
17) Seal stuffing box cap and attach water feed system;
18) If flowing artesian conditions exist, wait for pressure to stabilize and record pressure.
19) Note: a shut-in test can be carried out during the pressure stabilization (this will be described below);
20) Check inflation lines and inflation pressure to ensure no leaks occur, check water feeding system, prepare stop-watch and field test form
21) Packer system is now ready for testing.

5.0 PACKER TEST PROCEDURES

Procedures for various packer testing methods are described below. The procedures also include basic analytical procedures that can be applied (supporting equations are referenced in section 7 below).

5.1 Injection (Lugeon) Tests

Injection (Lugeon) tests consist of isolating a section of borehole and injecting water under pressure in to the rock to determine the effective transmissivity (T) of the zone. The transmissivity can be related to the hydraulic conductivity (K) of the rock or hydrogeological features (fractures, etc.) by means of $K = T/L$, where L = length of test zone).

The data recorded during the test simply consists of the flow rate and the corresponding pressure when "steady-state" conditions have been achieved. These data are recorded over a number of increasing and decreasing steps, as explained below.

5.1.1 Test Description

Based on the drill core, an assessment of the expected injection rates and pressure can be made. This will become easier as the testing program proceeds and the tester becomes familiar with the hydrogeological setting.

Observations of flow are made every minute until three consecutive, consistent readings are taken. This should represent steady-state flow. The pressure is then increased, usually for 5 equal increments, followed by 3 decreasing pressures. The steady-state flow at each pressure is recorded.

To begin the test, the tester will need to have an idea of the pressures to be tested (these are referred to as pressure steps A, B, and C below). The expected pressure range will be based on the estimated permeability of the rock and the expected intake of injected water. These will have to be assessed based on previous experience in the drillhole(s), and correlated to the pumping equipment available. If insufficient, or excessive, pressures are used for Pressure A, the test can be extended (more pressure steps for the former) or stopped and restarted for the latter at a lower initial pressure.

It is common practice to "ramp up" over at least three (3) "increasing" steps in the test, and to "ramp back down" two or three decreasing steps (at pressures that match the ramping up pressures). This is done to test for hysteresis in the plotted data. Deviation from a straight-line match can indicate hydrofracturing (if decreasing data is above the line) or non-Darcian flow (if decreasing data is below the line).

Note that it is assumed that injection losses due to friction losses in the drill rods will not be significant because of the large diameter. Friction losses through the packer assembly flow pipe would be significant, but the short length involved reduces this impact and so it will be ignored in subsequent calculations.

5.1.2 Basic Testing Procedures

Data should be plotted on a flow rate vs. pressure graph, for each pressure step. The shape of the plot, especially with regard to the decreasing pressure curve match, is used to assess the test results. This is described below in the Data Interpretation section (5.1.3).

The test usually consists of 3 to 5 ascending pressure steps, and 2 to 4 recovery pressure steps, as illustrated in the example below.

Pressure Step	Pressure (psi)
A	20
B	40
C	60
D	80
E	100
D_r	80
C_r	60
B_r	40
A_r	20

Note that step "B_r" refers to recovery pressure B, which should equal, or be similar, to ascending pressure step B

Using the expected initial pressure and estimated range of steps as a starting point, the following procedures are followed. If pressures and/or required pumping rates are not as expected, the tester will have to adjust the pressure steps as required.

The basic test procedures are as listed below:

1) Open water feeding system valve and maintain constant initial pressure A until it appears to have stabilized (often about 10-15 minutes);
2) During this time, record the elapsed time and total volume of consumed water every 0.5 min or so, for the first 2-3 min of the test stage, then every minute;
3) After pressure A has stabilized for approximately 3 minutes, increase the pressure to pressure B;
4) Record time vs. flow rate as for A
5) Increase the pressure, after pressure B has stabilized for approximately 3 minutes, to pressure C;
6) Test can be carried out for pressures D and E if the pump system has sufficient range left. The final pump rate should not be more than 80% of the maximum rate if possible;
7) Repeat pressure stage B (or last ascending pressure, D or C, if more than 3 steps used in test) – if formation is tight, release pressure by bypass valve on water feeding system to decrease pressure from C to B quickly;
8) Repeat pressure stage A – if formation is tight, release pressure by bypass valve on water feeding system to decrease pressure from B to A quickly;
9) After repeating stage A, perform recovery test: shut the feed valve and record pressure decrease vs. time for about 10-15 min, or until 90% recovery has occurred;
10) Deflate packer assembly and remove stuffing box cap and seal;
11) Wait until all nitrogen escapes from the packer cells, wait an additional 5 minutes and then pull the assembly carefully to top of drill rods, watching for the marker flag to prevent pulling assembly into overhead sheave; and
12) Measure groundwater level after the test several time to assess level recovery and static level.

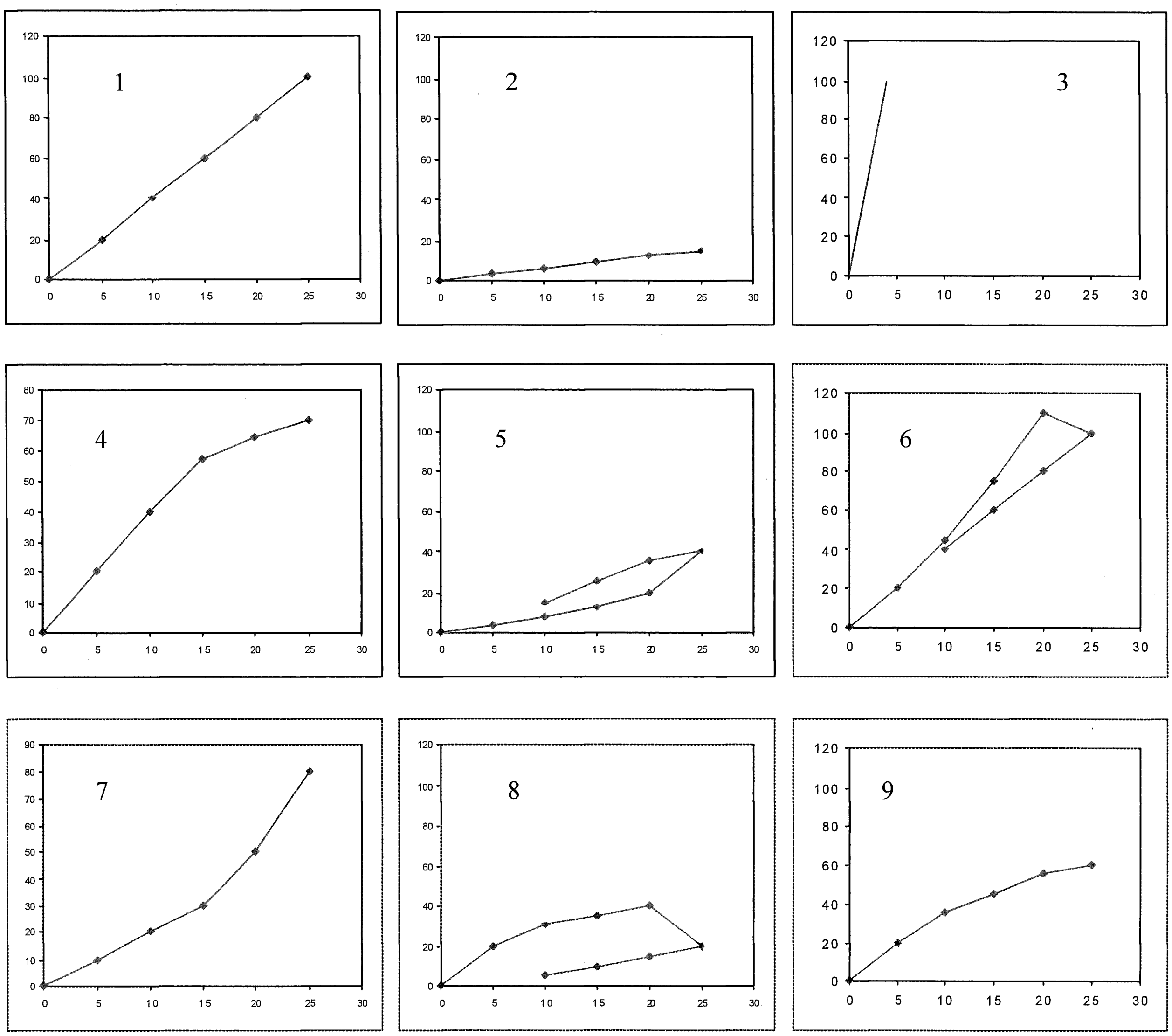
Test can be modified and made shorter or longer. One option is to perform only a constant head test with water level maintained near the head of drilling rods. When steady state occurs, measure flow-rate using calibrated bucket. Constant head test can be followed by simple falling head test with duration about 10-15 min.

5.1.3 Data Interpretation

The graphs in Figure 2 illustrate a selection of type curves, which are commonly observed. The following describes each curve. (Note that the recovery curve -reducing pressure curve- is indicated by a dashed line in the plots, otherwise the recovery curve is seen to mimic the ascending pressure curve).

1. Ideal result where flow is laminar, probably on clean fractures, discharge proportional to pressure head.
2. Tight fractures, impermeable material
3. Highly permeable, large open fractures. Water acceptance exceeds capacity of the test system and pressure recorded is due to friction in supply system.
4. Fairly high permeability with a decrease in flow with time due partially to a change from laminar to turbulent flow, as well as partial clogging of fractures with time.
5. Low permeability, but washing out of gouge material from the fractures, increasing the permeability.
6. Laminar flow, moderate permeability but with an increase in flow with pressure. Increasing packer pressure brings the flow back to a linear relationship with pressure, indicating increased flow was previous leakage past the packer.
7. Increase in permeability with increased pressure and the recovery curve follows the same path. This indicates that fractures have been opened up due to excess pressure (hydrofraccing).
8. Progressive decrease in permeability with pressure (and time) indicating incomplete blocking of the fractures by transported material.
9. Moderate permeability and flow rate is not linear. The down turned curve and similar recovery curve indicate that turbulent flow conditions exist beyond 15 bars.

FIGURE 2: Typical Flow vs. Pressure Curves



The data from the injection test can be used to determine the effective transmissivity (T) by means of the Thiem equation:

$$T = \frac{Q \ln\left(\frac{R}{r_b}\right)}{2\,\pi\,P_i}$$

where:

T	= transmissivity (m2/day);
Q	= injection rate (m3/day);
R	= radius of influence (m);
r_b	= radius of borehole (m); and
P_i	= net injection pressure (m).

5.1.4 Effective radius or radius of influence; *R*

Determining a reasonable value for *R*, the effective radius or radius of influence, is not a simple matter. This is because the parameter is a function of the hydraulic conductivity of the test zone, heavily influenced on variations in primary and secondary (fractures, etc.) permeability within the zone, specific storage of the rock mass and fractures, etc, test interval length, pump pressure, and time of test period.

However, as the parameter occurs within a natural logarithmic function, we can substitute a reasonable value. For example, if the drillhole radius is assumed to be approximately 0.04 m (1.5"), or approximately HQ wireline size, then values of *R* equal to 1, 5, 10, and 100 m would result in values of "$ln\ (R/r_b)$" equal to 3.3, 4.9, 5.6, and 7.9, respectively. Consequently, it can be seen that the *R* value used in the equation above will have a fairly insignificant effect on the value of *T* calculated using the equations for analysing the packer data. This is especially true when all the possible variables and potential cumulative errors in the testing process are taken into account. Therefore, it is considered that an R value of between 5 and 10 is reasonable and yields a reasonable value for *K*.

5.1.5 Net Injection Pressure; *Pi*

The net injection pressure is calculated as the combined pressure head (m) that is exerted on the test zone. It is calculated as follows:

$$P_i = P_g + h_g + h_s - h_f$$

where:

P_i	= net injection pressure (m);
P_g	= gauge pressure (m);
h_g	= height of gauge above ground level (m);
h_s	= depth to pre-test water level (m); and
h_f	= friction losses (m).

The sum of h_g and h_s is usually referred to as the column height. Both components of the column height should be measured before the test is carried out. The value for h_g should be the same for each test if the testing apparatus is not changed, but h_s will varying depending on the hydrogeologic zone penetrated by the drillhole.

5.2 Discharge Tests

5.2.1 Test Description and Basic Procedures

To carry out a discharge test, the packer is located at the drill bit in the same manner as for the injection test. The procedures for testing is fairly simple, but care must be taken to ensure a good packer seal as pressure response curves will not indicate leaking seals as in an injection test.

The following procedures outline the basic test set-up:

1. Locate drillbit and packer assembly as in an injection test;
2. Close flow valve at top of drill rods and monitor pressure;
3. After pressure has equilibrated (steady reading for at least 3 minutes), record shut-in pressure;
4. Start timer and record pressure vs. time logarithmically (i.e.: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 50, 60, 80, 100, 120, 150, 200, etc. minutes);
5. Plot data as Psi/Q vs. log10t (see below for parameter list).

5.2.2 Data Analysis

The apparent transmissivity of the packer isolated interval can be estimated from the time and discharge data using a modified Jacob-Lohman (straight line) equation:

$$T = \frac{2.30}{4\pi\left[\Delta\left(P_{si}/Q\right)/\log_{10} t\right]}$$

where:

T	= transmissivity (m^2/day);
P_{si}	= shut-in pressure (m).
Q	= discharge rate (m^3/day);
R	= radius of influence (m); and
t	= elapsed time since valve opened (min).

The simplest method of analysis involves plotting P_{si}/Q vs. $\log_{10}t$ and, with a best-fit straight line, estimating the change in P_{si}/Q over one cycle of t. Selection of the change in P_{si}/Q over one log cycle is not necessary, but simplifies the calculation since; in that case, the value of the term $\log_{10}t$ equals one. Therefore, the equation simply becomes:

$$T = \frac{0.183}{\Delta_1\left(P_{si}/Q\right)}$$

Where ? $_1(P_{si}/Q)$ indicates the change in P_{si}/Q over one log cycle of t.

5.3 Recovery Tests

5.3.1 Test Description and Basic Procedures

A recovery test is usually carried out in conjunction with a discharge test. Following the discharge test, the time is recorded (t), and the vale is again shut. This will allow the formation pressure to recover, with the relationship of time vs pressure recorded for this test.

The following procedures outline the basic test set-up:

1. Locate drillbit and packer assembly as in an injection test;
2. Close flow valve at top of drill rods and monitor pressure;
3. After pressure has equilibrated (steady reading for at least 3 minutes), record shut-in pressure;
4. Start timer and record pressure vs. time logarithmically (i.e.: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 50, 60, 80, 100, 120, 150, 200, etc. minutes);
5. Plot data as Psi/Q vs. log10t (see below for parameter list).

5.3.2 Data Analysis

The pressure readings are plotted against log10(*t/t'*), the log10 ratio of the time since the discharge test started (*t*) over the time since the recovery test has started (*t'*). The apparent transmissivity of the test interval can be estimated using the Cooper-Jacob method:

$$T = \frac{2.30\,\overline{Q}}{4\pi\left(\dfrac{\Delta P_r}{\Delta \log_{10}(t/t')}\right)}$$

where:

T	= transmissivity (m^2/day);
$\overline{Q}$	= average discharge rate during the discharge period (m^3/day);
? P_r	= change in recovery pressure (m).
t	= elapsed time since start of discharge test (min); and
t'	= elapsed time since valve closed (min);.

Similarly to the plot for the discharge test, the analysis is simple if the change in recovery pressure is taken over one log cycle of t/t' (where, again, the term log10(t/t') equals 1. In this case, the first equation can be simplified to:

$$T = \frac{0.183\,\overline{Q}}{\Delta_1(P_r)}$$

Where ? $_1(P_r)$ indicates the change in recovery pressure over one log cycle of *t*.

6.0 TESTING TROUBLE SHOOTING

6.1 Test QA/QC

To ensure that the data collected during the test is accurate, and more importantly, representative of the zone of interest, the tester must verify that the test assembly is not leaking. Leaks through the supply line or rods, or past the packers will have the effect of apparently increasing the permeability of the test zone. This is because water pumped during the test will be assumed to be flowing into the test zone, but will instead be a combination of zone uptake and leakage. This will become more significant as permeability of the zone decreases and/or the injection pressure increases.

Potential Areas where Leaks can occur

a) Packers (bypass);
b) Injection pipe joints;
c) Drill rods

6.2 Packer Bypass Leakage

A common area where a leak can occur is past the packer, between the expanded gland and the drillhole wall. Incomplete inflation, irregularities on the drillhole wall, tears in the outer gland material, etc are likely reasons for this to happen. Leakage of this type is difficult to assess as flow past the packer and that into the zone cannot be distinguished at surface. In order to determine if the packers are sealing properly, various information is available to the operator:

1. Check for a drop in packer inflation pressure during the test. A drop in pressure will indicate that the packer is deflating (and it or a supply line is probably leaking);
2. Check for bubbles if using a pneumatic system and the water level is visible at the top of the drill rods; and
3. Note unexpected flow vs. pressure performance either within a single test or as compared to other test zones of similar rock (as determined from the drill core). This may indicate that more water is being "taken" by the zone, whereas it is in fact leakage.

It will probably be necessary to remove the packer assembly, test it, and re-run the test in order to verify that the data collected is representative and accurate. This will be time consuming, but overestimating the zone K due to poor data collection could have serious consequences on later engineering design considerations.

6.3 Drill Rods Leaks

The joints in the drill rods should be "wicked" in order to reduce leakage. Wicking consists of wrapping a string or wicking material around the rods threads prior to connecting rods. The leakage may be greatly reduced, but may still have a significant effect when the cumulative leakage is taken into account. To test for the apparent leakage, it is recommended that at "blind" packer assembly is lowered to just above the bit and inflated. Water is then pumped into the rods and the flow vs. pressure response is recorded. If it is assumed that the packers are sealing the rods, and that water is not flowing through the bit, then any flow will be the cumulative joint leakage. The pump pressure should correspond to the expected test pressures, with a 150% increase in order to test the system (note: do not exceed 80% of packer inflation pressure as this will potentially force water past the gland, regardless of proper inflation or not.)

6.4 Supply Pipe Leaks

Testing an independent supply line can be done on surface. The only modification required is to block the water injection pipe at the bottom of the upper packer using a plug threaded to fit. Testing pressures should be the same, except that allowance for packer inflation pressure is not required.

7.0 REFERENCES

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